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A SHORT STORY OF CHARLES BABBAGE AND HIS CALCULATING MACHINES

Part One

January, 1905

WYMAN & GORDON
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WORCESTER, MASS

A Short Story of
Charles Babbage
and his
Calculating Machines

PART ONE

January 1903

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Cleveland, Ohio — Worcester, Mass.

CHARLES BABBAGE

THIS Short Story will be divided into Two Parts, on account of the space necessary to describe, even in the briefest manner, the inventions of this most remarkable man. Very little is known about his home life, although he lived very recently; the invention so far transcended the man in importance, that the details of his life seem to have dropped out of sight.

Charles Babbage was born on the 26th of December, 1791, at Totnes, Devonshire, England. His parents were wealthy and sent him to a private school to be educated.

He entered Trinity College, Cambridge, in 1810. He early showed a marked interest in mathematics, and it is recorded that he was familiar with the works of the great mathematicians before he went to college. He graduated from Trinity in 1814 with high rank in mathematics, then traveled and continued his studies privately. His first published essay was on the Calculus of Functions, in the Philosophical Transactions of 1815. He was made a fellow of the Royal Society in 1816, and labored with Herschel and Peacock to raise the standard of mathematical instruction in England.

He early noticed the number and importance of errors in astronomy and other calculations due to errors in mathematical tables. (The first idea of a calculating machine came to him in 1812 or 1813, while still a student. Some years later he went to Paris to study

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their methods for computing and printing the now celebrated French tables of powers, roots, circumferences, areas, sines, tangents, logarithms, etc. There he met several of the most noted mathematicians of the day. He bought a copy, at a high price, of Didot's natural sines, carried to the twentieth place in figures. By the permission of the French officials, he copied by hand to the fourteenth place, from the tables of logarithms deposited in the Observatory, every 500th number from 10,000 to 100,000.

All scientific callings require these tables, but especially astronomers and navigators. These tables are now seen in every engineer's hand-book, and we little appreciate the labor and expense involved in their preparation. It is of interest to consider the extreme care that was taken to prepare them. The work of calculating these tables was entrusted at Paris to three corps of calculators, the first section investigated the various formulae and selected the ones that could most readily be adapted to simple numerical calculation by many individuals. The second section consisted of seven or eight trained students, who converted the algebraic formulae into numbers and tabulated and reviewed the calculations of the third group. The third section consisted of sixty to eighty persons, who simply added and subtracted the equations given them. Their labors occupied several years and the results were bound in 17 folio volumes. In these tables absolute accuracy is essential, and that is very, very rarely attained. In a set of logarithms stereotyped by Mr. Babbage, the proof was compared number by number with other tables seven times, never-the-less, in the last reading thirty-two errors were discovered.

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After stereotyping the proof was compared figure by figure four times and eight more errors discovered. Other tables, after having been in use for years, have been found to contain hundreds of errors.

Becoming intensely interested in these tables and the methods for preparing and copying them, Mr. Babbage, as early as 1819, gave careful thought to the invention of a machine that would calculate and print them without the intervention of human hands and, therefore, without error. By 1822 he had made a small machine that would calculate simple formulæ, such as multiplication tables and squares up to eight figures.

In a letter of this same year to the President of the Royal Society, he not only describes this machine, but adds that he had already designed a method for printing faultlessly the results, and that he also had in mind machines to multiply, extract roots, and various other operations.

The machine that was constructed at this time was very simple, consisting of but few parts, but these were repeated many times. On trial, it was found possible to calculate from 30 to 40 numbers a minute, which was faster than a man could copy them down. He claimed that his machine only needed to be constructed on a larger scale to calculate any and all tables that were characterized by regular differences between succeeding terms, and to add printing mechanism that would produce and record absolutely faultless tables.

He called this first machine a Difference Engine, because it produced successive terms of a table automatically, by adding the requisite differences to the last term.

To illustrate in the table of squares, 1–4–9–16–25, etc.

By subtraction we get the first order of differences, 3–5–7–9, etc.

By subtraction again we get the second order of differences, 2–2–2, etc.

Now, to find any term, we have only to add the constant 2 to the last known difference of the first order to the last known square, to produce the following square:

To illustrate, what is the square of 11? The square of 10=100, the square of 9=81, 100—81=19 2+19+100=121, the square of 11. This is comparatively a simple table. There are tables in common use that have five, six, and even seven orders of differences, before the constant is found. Mr. Babbage, in 1822, wrote to the Prime Minister of England and asked Government assistance in constructing a Difference Engine that could calculate up to twenty places of figures, and that would also print automatically the results.

The Treasury referred the request to the Royal Society, for an opinion as to the merits of the invention. They reported promptly that it was "fully adequate to the attainment of the objects proposed by the inventor." Soon after, in 1823, the sum of $7,500 was appropriated to this end.

Mr. Babbage at once set to work to construct the enlarged and automatic Difference Engine. Draftsmen were set to work making the drawings. Mr. Joseph Clement, out of Maudsley's men, was given charge of the mechanical part, and for four years the work proceeded. Tools had to be designed and constructed to

meet the demand for extreme accuracy, even workmen had to be trained to a nicety of execution before unheard of.

In 1827 the expense incurred had amounted to $17,000, of which Mr. Babbage had advanced nearly $10,000. At this time his health was poor and he went to Italy, leaving minute instructions to be followed in building the machine and placed $5,000 at their disposal. Perceiving that the probable expense would be considerable, he asked the Government for another grant. Lord Wellington inquired of the Royal Society for an investigation as to whether the project was worth proceeding with. The Society gave "their decided opinion in the affirmative." In 1829 the Government made another grant of $7,500. By this time the expense had reached $35,000. Lord Wellington then personally examined the machine, and the Government made a grant of $7,500 more, with the suggestion that the calculating part be separated from the printing device.

In 1830 still another grant of $15,000 was made by the Government. In 1832 the Government constructed a fire proof workshop near Mr. Babbage's residence to contain the costly drawings and machinery which had accumulated during the years. In 1833 a portion of the machine was put together, which completely justified the expectation. It could calculate, and did so with absolute accuracy, tables of three orders of differences up to sixteen figures.

Meanwhile difficulties arose between Mr. Babbage and Mr. Clement, who had charge of the construction. The latter had an increasing sense of the value of his part of the work, and his charges grew apace. At

length Mr. Babbage secured consent to have Government Engineers examine all accounts before being paid. There being some delay in payments, Mr. Babbage was accustomed to advance money. In 1834, he declined to do this longer, and the result was that Mr. Clement withdrew, taking with him many of the best workmen and all the special tools that he had designed and built, which according to the custom of the day he had a right to do, even though the Government had paid for them. Then there were vexatious delays, as to whether the Government would meet Mr. Clement's terms or secure some one else for the construction.

Meanwhile an entirely new idea came to Mr. Babbage by which he could construct a calculating machine of far greater range than the Difference Engine. Mr. Baggage felt that it was not right to ask the Government to complete the first machine without making known to them his new discovery. Perhaps also, and it would be quite natural, he rather hoped that the Government would abandon the old and start at once the construction of the new. At any rate, while the question was being discussed, political questions became involved and the matter was not decided until 1842, when it was definitely given up. The part of the machine that was completed was sent to the Museum of King's College, London, and later sent to South Kensington and the uncompleted parts distributed among friends and institutions, as souveniers.

The entire cost of this machine to the Government, exclusive of the fire proof building, had been $80,000. Not one penny came to Mr. Babbage as a recompense for his labors of twenty years. In addition to what the

Government had expended on the construction, Mr. Babbage had also expended fully as much more and considerable sums for personal expenses, experiments, travel, and research. Although this machine was never completed, it has been thought by some that the money had been well expended, because of the habits of extreme accuracy and precision that were introduced into English machine construction, by the many workmen and draftsmen who received their training under Babbage and Clement and then passed on to other shops, carrying with them the skill and method there acquired.

The construction of machine tools was certainly greatly enriched by the necessities involved in the construction of this invention.

From 1828 to 1839, Mr. Babbage had been Lucasian Professor of Mathematics at Cambridge. He had made several journeys to the Continent and written many letters and essays. One book, published in 1834, called "The Economy of Machines and Manufactures," summed up his consideration of the manufactures of the time. This book was widely printed and read for several decades, and did much to extend the modern system of manufacture by machinery.

Once only, in 1832, he tried to enter public life, but was defeated.

In our next number the story of Mr. Babbage will be continued with an account of his greatest invention, the Analytical Engine, which was the most complicated mechanism ever conceived by the mind of man.

DWIGHT GODDARD.

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A SHORT STORY OF

CHARLES BABBAGE

Part II.

The Analytical Engine

March, 1905

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CHARLES BABBAGE

PART 2

THE ANALYTICAL CALCULATING MACHINE

IT WAS not decided by the Government of England to discontinue the construction of the Difference Machine until 1842, almost ten years after work upon it had ceased. Meanwhile Mr. Babbage had given much thought and expense in perfecting his new and vastly more complicated calculating machine.

The Difference Engine was designed to calculate tables by simple addition of the proper differences. The Analytical Engine was designed to work out the algebraic development of any formula whose law was known and to convert it into numbers. In fact, Mr. Babbage declared that if constructed it could solve any algebraic problem the successive steps of which could be conceived of by the human mind, do it automatically and print the result without the possibility of error.

In a letter Mr. Babbage thus describes it:

"It is intended to include 100 numbers, susceptible of changing—each may consist of 25 figures * * * any given function which can be expressed by addition, subtraction, multiplication, division, extraction of roots, or the elevation of powers, the machine will calculate its

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numerical value; it will afterward substitute this value in place of V or any other variable and will calculate the second function with respect to V; it will reduce to tables almost all equations of finite differences."

In the Difference Engine the exact method for adding was immaterial because a simplification of it only affected one or two hundred parts, but in the Analytical Engine, the mechanism for performing the elementary operations of adding, subtraction, dividing and multiplying became so important that any change affected thousands upon thousands of parts. In fact the machine could only exist by inventing for it a mechanical method of addition of the utmost simplicity. It is said that Mr. Babbage and his assistants designed and partly constructed over twenty different methods before the desired simplicity was attained.

The system of addition finally decided upon was extremely simple and yet it not only added all digits at once, but included in the total all amounts carried and what is more wonderful, had an "anticipating carriage," that included in the total all the amounts carried of the carryings. Thus any addition could be performed automatically at one operation, without the necessity of a subsequent operation to include the carryings.

The Engine was not a combination of machines, the one to add, another to subtract, another to divide, but was designed as one machine, so arranged that any operation, or any combination of operations, could be performed automatically at will. It consisted in the main of two sets of columns, the one called the Mill and the other the Store.

The Mill consisted of a series of columns made up of discs, into which was placed the quantities about to be operated. The Store consisted of a larger number of columns into which all the variables about to be operated upon were placed, and into which all those quantities, which had arisen by result of other operations were placed.

He thus separated the operations from the objects acted upon.

"All the shifts which have to take place, such as carrying, borrowing, etc.—changing addition into subtraction, or shifting the decimal place, are affected by a system of rotating cams, acting upon or actuated by bell cranks, tangs, clutches, escapements. These clutches and bell cranks control the process effected, or being themselves suitably directed, secure that the proper process should be performed on the proper subject matter and duly recorded or used as required."

The columns that make up the Store contained a series of wheels that received the results of operations performed by the Mill and served as a store of numbers yet to be used. The wheels gear into a series of racks, which in turn are operated by cards.

These cards were the new thought that came to Mr. Babbage when he was constructing the Difference Engine and which brought him visions of the possibilities of the new machine and led him to lose interest in the old.

The cards themselves were no new invention. They were invented by Jacquard to control the introduction of threads in weaving brocade. It flashed into Mr. Babbage's mind that he could use these cards to indicate

successive operations in a calculating machine that, with this equipment, would have a power over complicated arithmetical operations that would be nearly unbounded.

These cards were perforated by different combinations of holes and were then linked together as a chain and arranged to pass successively over a set of wires. The wires, corresponding to the holes, would drop through and indicate by suitable connections the desired operations of the Mill.

Having the machine, all that human brains are called upon to do is to perforate successive cards and then operate the machine, when the desired operations would follow without possibility of error.

In the Analytical Engine there were two principal sets of these cards, one to indicate operations, one to indicate the columns of variables upon which the results are to be presented.

These cards thus arrange the various parts of the machine and then execute the processes.

ILLUSTRATION.

$$(1) \quad mx + ny = d$$

$$(2) \quad m'x + n'y = d'$$

$$(3) \quad x = \frac{dn' - d'n}{mn' - m'n}$$

$$(4) \quad y = \frac{d'm - dm'}{mn' - m'n}$$

To find the value of x and y eleven successive operations must be performed, as indicated in the following tables:

Columns on which are inscribed the primitive data.	Number of the operations.	Cards of the operations.		Variable cards.			Statement of results.
		Number of the Operation-cards.	Nature of each operation.	Columns acted on by each operation.	Columns that receive the result of each operation.	Indication of change of value on any column.	
$^1V_0 = m$	1	1	$\times$	$^1V_0 \times {}^1V_4 =$	$^1V_6$	$\left\{\begin{array}{l} ^1V_0 = {}^1V_0 \\ ^1V_4 = {}^1V_4 \end{array}\right\}$	$^1V_6 = m n'$
$^1V_1 = n$	2	”	$\times$	$^1V_3 \times {}^1V_1 =$	$^1V_7$	$\left\{\begin{array}{l} ^1V_3 = {}^1V_3 \\ ^1V_1 = {}^1V_1 \end{array}\right\}$	$^1V_7 = m' n$
$^1V_2 = d$	3	”	$\times$	$^1V_2 \times {}^1V_4 =$	$^1V_8$	$\left\{\begin{array}{l} ^1V_2 = {}^1V_2 \\ ^1V_4 = {}^0V_4 \end{array}\right\}$	$^1V_8 = d n'$
$^1V_3 = m'$	4	”	$\times$	$^1V_5 \times {}^1V_1 =$	$^1V_9$	$\left\{\begin{array}{l} ^1V_5 = {}^1V_5 \\ ^1V_1 = {}^0V_1 \end{array}\right\}$	$^1V_9 = d' n$
$^1V_4 = n'$	5	”	$\times$	$^1V_0 \times {}^1V_5 =$	$^1V_{10}$	$\left\{\begin{array}{l} ^1V_0 = {}^0V_0 \\ ^1V_5 = {}^0V_5 \end{array}\right\}$	$^1V_{10} = d' m$
$^1V_5 = d'$	6	”	$\times$	$^1V_2 \times {}^1V_3 =$	$^1V_{11}$	$\left\{\begin{array}{l} ^1V_2 = {}^0V_2 \\ ^1V_3 = {}^0V_3 \end{array}\right\}$	$^1V_{11} = d m'$
	7	2	$-$	$^1V_6 - {}^1V_7 =$	$^1V_{12}$	$\left\{\begin{array}{l} ^1V_6 = {}^0V_6 \\ ^1V_7 = {}^0V_7 \end{array}\right\}$	$^1V_{12} = m n' - m' n$
	8	”	$-$	$^1V_8 - {}^1V_9 =$	$^1V_{13}$	$\left\{\begin{array}{l} ^1V_8 = {}^0V_8 \\ ^1V_9 = {}^0V_9 \end{array}\right\}$	$^1V_{13} = d n' - d' n$
	9	”	$-$	$^1V_{10} - {}^1V_{11} =$	$^1V_{14}$	$\left\{\begin{array}{l} ^1V_{10} = {}^0V_{10} \\ ^1V_{11} = {}^0V_{11} \end{array}\right\}$	$^1V_{14} = d' m - d m'$
	10	3	$\div$	$^1V_{13} \div {}^1V_{12} =$	$^1V_{15}$	$\left\{\begin{array}{l} ^1V_{13} = {}^0V_{13} \\ ^1V_{12} = {}^1V_{12} \end{array}\right\}$	$^1V_{15} = \frac{d n' - d' n}{m n' - m' n} = x$
	11	”	$\div$	$^1V_{14} \div {}^1V_{12} =$	$^1V_{16}$	$\left\{\begin{array}{l} ^1V_{14} = {}^0V_{14} \\ ^1V_{12} = {}^0V_{12} \end{array}\right\}$	$^1V_{16} = \frac{d' m - d m'}{m n' - m' n} = y$
1	2	3	4	5	6	7	8

Cards for these variables must be arranged and cards for the eleven operations and then all that remained was to place the mechanism in motion. It is thus seen that anything in the way of calculating that the human mind is capable of precisely defining, this machine would be capable of performing.

Anyone at all versed in designing machinery will recognize the difficulties involved in keeping a clear conception of the individual motions of this maze, of "wheels within wheels." In order that he might have a clearer insight into the various motions, Mr. Babbage invented a system of mechanical notation, by means of which he

could chart the syncronous motions of every part of even the most complicated mechanism. The motion of each part was represented by a vertical line, whose length was divided into units of motion. On each side of this line were various symbols for direction, nature (intermittent or regular), source, etc. These tables of notation were carried to such refinement that in designing it was always possible by laying a straight edge across the chart to see at a glance the exact position and status of every part at that instant.

It is said that at one stage it was desirable to shorten the time in which a certain operation was performed. The constructor had a model of the part before him, while Mr. Babbage resorted to his tables. The operation required the time of twelve revolutions. After prolonged study, they found ways to reduce the time to eight revolutions, then the Constructor gave it up, but shortly after Mr. Babbage discovered new combinations by which it was crowded into four revolutions.

For twenty years Mr. Babbage continued work on this invention in his own house and at his own expense. He continuously employed draftsmen and mechanics, and took much time in explaining his designs to visiting experts, mathematicians, and philosophers.

It was no dream of a crank. It was the consummate result of the life-long thinking of the greatest genius for this sort of thing that the world has ever seen. The designs were examined by the wisest philosophers and the foremost engineers of his day, who again and again gave commendation and endorsement to the worth of his plans.

To be sure, only a small part of the Mill was ever built, just sufficient to show the method of adding and subtracting and the anticipating carriage. Part was made in gun metal mounted on steel, but the greater part of a kind of pewter hardened by zinc and moulded by pressure. All the principles were either drawn or constructed in models.

A great many experiments were made and special tools designed for making with sufficient precision the multitude of little wheels, which, in some cases, amounted to 50,000, and the various methods of construction were determined upon. Over 400 drawings were made, of which some thirty were group plans, some of which were of elaborate complication. There are five volumes of sketches, and 400 to 500 folio pages comprising a complete mechanical notation.

There was very little description made of it. The philosophers were more interested in speculation over its mathematical possibilities and Mr. Babbage was too busy designing until the infirmities of old age prevented him. He once, however, spoke of 1,000 columns with 50 wheels each in the Store alone, and, besides, many thousand wheels mounted on axles in columns for the Mill and a vast machinery of cams and cranks for the control.

It was a marvel of mechanical ingenuity and resource, in detail good, but, on the whole only a theoretical possibility. Probably no man but Mr. Babbage himself ever understood its working.

M. Menabrea, an Italian Military Engineer, made a profound study of it in 1842, but admits in his careful

description that the time at his disposal was gone before he had begun to master its more abstruse possibilities.

The Analytical Engine was invented in 1834, and it was 1848 before Mr. Babbage felt that he had mastered its main design. In 1852 he consulted the Government to see if they would construct it, and in 1854 he abandoned work upon it.

He had doubtless expended over $100,000 of his private fortune on the two machines. Those who were cognizant of the state of machine construction during these years aver that the money expended was more than repaid in the advance caused in the art of constructing machines of precision. No small credit should be given to Mr. Babbage for this exceedingly practical result of his painstaking efforts.

The printed works of Mr. Babbage comprise over 80 titles nearly all of which are essays on mathematical and philosophical subjects. He died in London in 1871.

CHARLES BABBAGE

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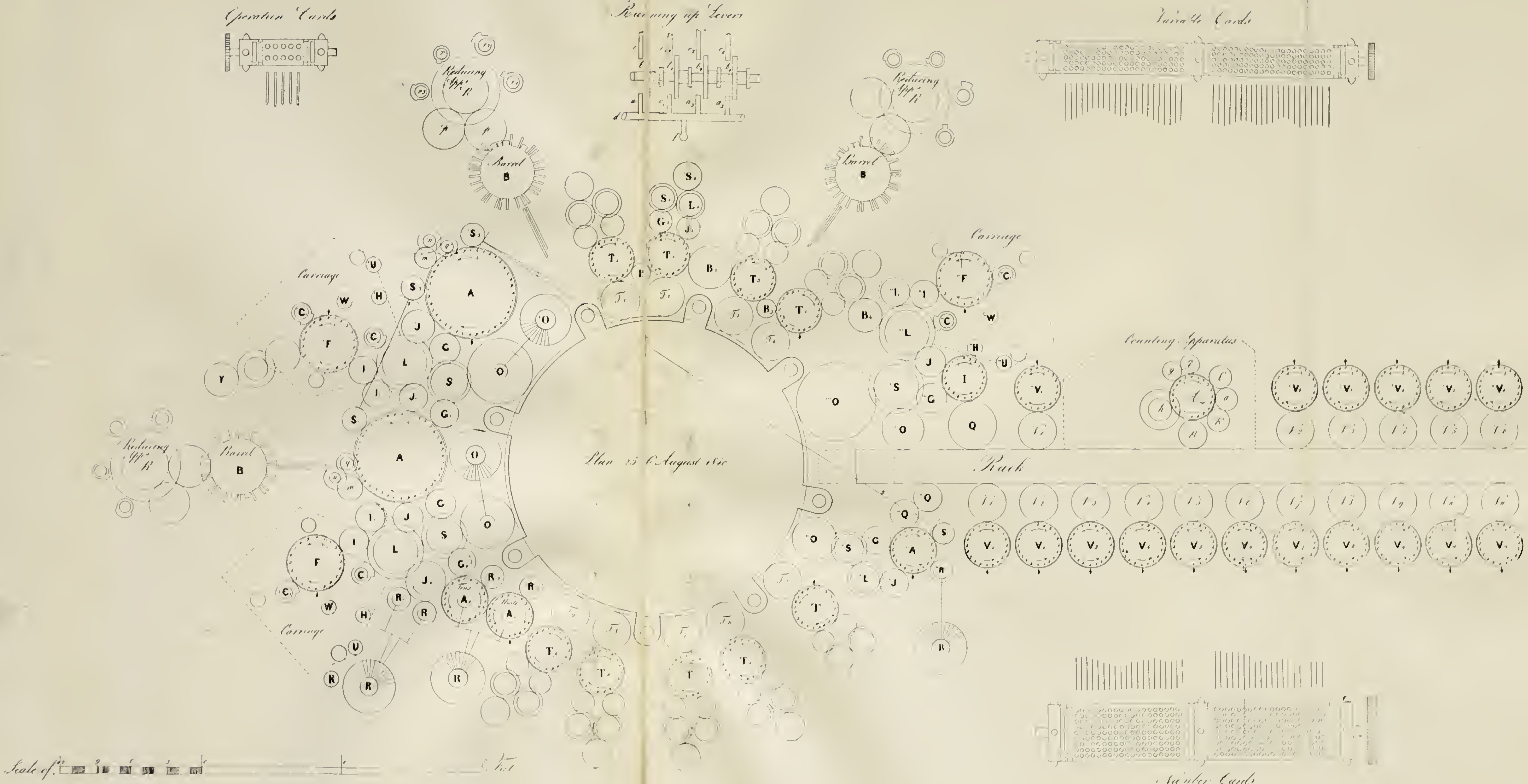
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